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Potential for developing run-of-river systems in eastern Kentucky : a GIS approach to site suitability.

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POTENTIAL FOR DEVELOPING RUN-OF-RIVER SYSTEMS IN EASTERN KENTUCKY:

A GIS APPROACH TO SITE SUITABILITY

By

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A Thesis

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A Thesis Approved on

April 24, 2018

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ABSTRACT

POTENTIAL FOR DEVELOPING RUN-OF-RIVER SYSTEMS IN EASTERN KENTUCKY:

A GIS APPROACH TO SITE SUITABILITY

Thomas Jeffords

April 24, 2018

Coal has a questionable future with the potential exhaustion of available coal. Alternate sources of energy production should be considered, such as hydropower dams, or the more environmentally friendly, Run of River (RoR) hydropower system. This study seeks to answer the question: What is the potential for RoR hydroelectric systems in Eastern Kentucky counties with significant decreases in coal production and employment? I hypothesize that GIS will identify suitable sites within Pike County for RoR systems.

Site suitability for Eastern Kentucky was assessed and determined that Pike County did not have a suitable physical environment for RoR systems. The power generation was too low for efficient use. Future studies could expand the research into other locations, focusing on watersheds with the most potential. With appropriate landscape requirements, RoR systems have a smaller environmental impact than traditional dams, and potential for economic benefit from producing jobs and energy supply.

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CHAPTER 1: INTRODUCTION

1.1 Coal's Questionable Future

As Earth's finite energy resources are continually used and go through economic fluctuations, the need for more sustainable sources of energy become more important. The USGS preliminary proposal (2015) indicates that coal production in Central Appalachia has been decreasing since its peak in 1990, seeing large losses in demand between 2006 and 2011 with the large decrease in use of the electricity sector. Coal production for Central Appalachia is projected to continue to decrease by about 53% between 2011 and 2040 as market prices, labor productivity, foreign competitors, and national demand undergo changes (Milici 2000 and McIlmoil et al. 2013). Additionally, on a global scale, coal production is expected to peak in 2050 with China becoming a leading producer, although their reserves are not fully known and many studies debate their peak production based on reserves and potential production (Zaipu and Mingyu 2007; Lin and Liu 2010). Although studies predict there to be hundreds of years of geologically available coal, not all of it is feasible for recovery. Technological improvements are helpful, but the biggest factor is economic sustainability (Höök et al. 2010). Ruppert et al. (2002) suggests that less than one half of available coal can be recovered due to mining restrictions, and only about one-tenth of the geologically available coal is recoverable based on economic restrictions.

1.2 Renewable Energy Resources

A solution to this issue is to develop alternative sources of energy and revenue. One method is to use renewable sources for energy such as solar, wind, and hydro power. These methods can be considered clean energy with a lower impact than burning fossil fuels, but they still can have an impact on the surrounding environment (Akella at al. 2009). For hydro power, dams are built to collect water that can pass through turbines to generate energy based on the hydraulic head and discharge of the waterway (Lyndon 1916; Renewables First 2015). Hydropower is the amount of electricity that is generated, and energy is derived from this generation further by multiplying by a time variable (Oregon State University 2002). Because reservoir or impounding dams store a large amount of water to create an artificial head, the natural flow of the waterway is altered, resulting in various environmental impacts (The Constructor 2017). Graf (2006) reviewed literature on downstream effects of 36 large dams throughout the U.S to quantify hydrologic and geomorphic changes. Not only do the findings show that larger dams have a significant impact on downstream hydrology and geomorphology, but there is regional variation between dams that adds to the complexity of the issues, such as differences in rivers as described by Benke and Cushing (2005). Some of the hydrologic results of the study show peak flow was reduced after being controlled with dams, which could overall have negative impacts on riparian areas that are dependent on flooding (Doyle et al. 2005). Many areas have grown to survive in flood plain areas and those areas can be impacted as well. It was also noted that because of the low flow and high flow dates that large dams rotate between, avian species may try to nest during low flow, and if the dates change then there can be effects on bird populations. Geomorphic effects show the standard active areas of rivers are reduced considerably, sometimes up to 91% less area, showing large dams' great ability to modify hydrologic regimes (Graf 2006). Ecological implications from the study included changes in vegetation habitat for downstream areas that are important to wildlife. Biodiversity changes occur with changes in the hydrologic regime. Magilligan and Nislow (2005) as well as Yang et al. (2007) studied how dams change the amount and distribution of sediment that travels downstream, causing ecological and water quality impacts. Species diversity in aquatic habitats are impacted when a change in sediment transport occurs from dam constructions. Construction and maintenance can cause critical areas like spawning surfaces to be covered in sediment fines upstream of the dam. Conversely, a reduction in flow from the dam would reduce sediment and nutrients from moving downstream as resources that some species would have originally depended upon.

1.3 Power and Energy Generation

Typical hydropower dams store large amounts of water to produce their own hydraulic head, which is the measurement of liquid pressure above a geographically referenced coordinate system. Water is channeled through turbines to create electricity. Large dams in U.S. represent over 20 GW of electricity capacity (2%) (Energy Storage Association 2017). Electricity is produced in the form of energy. Energy is measured in joules (j) in the International System of Units and one joule is equal to 1 watt second in electricity (Encyclopedia Britannica 2017). A watt (W) is a measurement of power through how much energy is used over time. There are 1,000 watts in a kilowatt (kW), which is how most watt unit power is displayed. In terms of time, a kilowatt hour (kWh) explains the amount of energy used for 1 kW of power in an hours' time. Home energy reports are often explained in terms of kWh (IGS Energy 2016). Larger power usage are displayed in megawatt (MW) (1,000 kW) which is typically how hydroelectric storage dams explain power generation. For example, the Hoover Dam, which is mainly used for flood control, but does have hydropower capabilities, has a 2,000 MW capacity, and produces 4.5 billion kWh of power a year for 8 million people in the Southwest United States (Arizona Power Authority 2012).

1.4 Run-of-River Systems

A method of attaining hydropower with a smaller environmental, economic, and social impacts includes a form of distributed renewable energy called run-of-river systems (RoR) (USGS Preliminary Proposal 2015). Distributed energy systems convert power in locations close to energy consumers, as opposed to centralized units like power plants (Alanne and Sarri 2006). RoR distributed energy systems have lower power capacity and lower costs/impact ratio that could be seen as beneficial to local communities (McIlmoil et al. 2012). This system works by creating a small upstream pond called a weir that keeps a steel pipe (penstock) submerged. The penstock transports water down to a power house where turbines generate the power. The energy is directly fed to transmission lines instead of being stored, and the water is returned to the river at the end of the RoR system. There are different levels of these systems from small to micro power generators ranging from about 30 MW to less than 100kW. These systems can be considered RoR as long as they do not have a significant impact on the natural flow of the stream and have a smaller environmental impact than traditional hydropower storage dams (USGS 2015). A study in Oregon on the South Fork Coquille River, and the Chetco River reveal some potential for RoR energy generation. Some low discharge measurements (5-10 cfs) yielded ~ 4-8 kW, coming to ~37,000 to 74,000 kWh per year. Higher discharges (55-120 cfs) resulted in 46-101 kW, at ~407,000 to 880,000 kWh per year (Oregon State University 2002). For perspective, according to the U.S. Energy Information Administration, the 2015 average annual electricity consumption per household for the U.S. was about 10,812 kWh, at about 901 kWh per month. (EIA 2016).

1.5 RoR Considerations

As pointed out by Rojanamon et al. (2009), there are social, economic, engineering, and environmental aspects that need attention when implementing RoR systems. Important points from Rojanamon et al. (2009) that will aid this study are their GIS applications using digital elevation models to find waterways with proper a hydrologic head (which is usually no more than 30ft), discharge estimations to accompany various head heights, and determining downstream environmental impact of the RoR implementation. Using this analytical framework, Rojanamon et al. (2009) were able to identify potential sites that met all of their criteria and proved the ability to review a large area for RoR potential in the Nan River Basin of Thailand.

An additional study by Anderson et al. (2015) focused on the environmental impact of RoR systems. Even though the RoR systems are an improvement to conventional hydro/turbine dams, they determined that there is evidence of potential disruption in the habitat availability, structure of biological communities, and potential for sediment transport and fish migration changes. Changes in the temporal and spatial scale of the RoR systems yielded differing levels of environmental impact. In the conclusion of their study, they outline several suggestions for moving forward when implementing RoR systems, such as including experimental phases in development with before-and-after impact studies. They also recommended a greater level of interdisciplinary studies when developing hydro energy systems, such as hydro-morphological and ecological research. They outlined the importance of hydro energy as well as its growth, while making sure to identify potential issues to be aware of that could help make RoR systems more environmentally friendly.

Other studies have looked at aspects such as the size of the hydropower plants based on turbines and discharge (Anagnostopoulos and Papantonis 2007). This study was helpful in determining the optimal size, quantity and combination of turbines commonly used in the RoR systems giving them the ability to indicate the general procedure and equipment for different financial or hydrologic conditions. Additionally, cost of implementation is important as covered by at by Singal et al. (2010) and Okot (2013). Some advantages identified were the low operating costs, long lasting technology with systems that could last 50 to 100 years, and the availability of employment opportunities. A big cost disadvantage are the high capital costs for implementation. Difference in hydraulic head also changed costs with lower head having a higher cost, and requiring a bigger discharge than high head RoR systems. There is variation in costs of implantation depending on location. The cost per kilowatt changes based on labor costs, number of sites, and site condition parameters (Singal et al. 2010).

This study will employ a GIS-based analysis to evaluate the suitability of Eastern Kentucky for RoR systems in order to answer the question: What is the potential for run of river hydroelectric systems in Eastern Kentucky counties with significant decreases in coal production and employment? I hypothesize that there were suitable sites within county or watershed level locations in Eastern Kentucky for RoR systems, as determined through GIS.

Using GIS to determine suitable locations for RoR systems is ideal when reviewing large regions, and opens the possibility for more studies and hydro power implementation. An improved mindset of environmental awareness means RoR systems could be a great asset to renewable energy production.

CHAPTER 2: STUDY AREA

Identifying counties in Eastern Kentucky for the study were achieved using information from Kentucky Coal facts (2016). Initially, only the counties that have had the largest percent decrease in coal production and employment were studied. Pike County had a 33.69% decrease in production between 2014 and 2015, which was one of the largest decreases. Additionally, Pike County has several stream gauges (Figure 1) recording discharge, a key variable required for any RoR site development analysis.

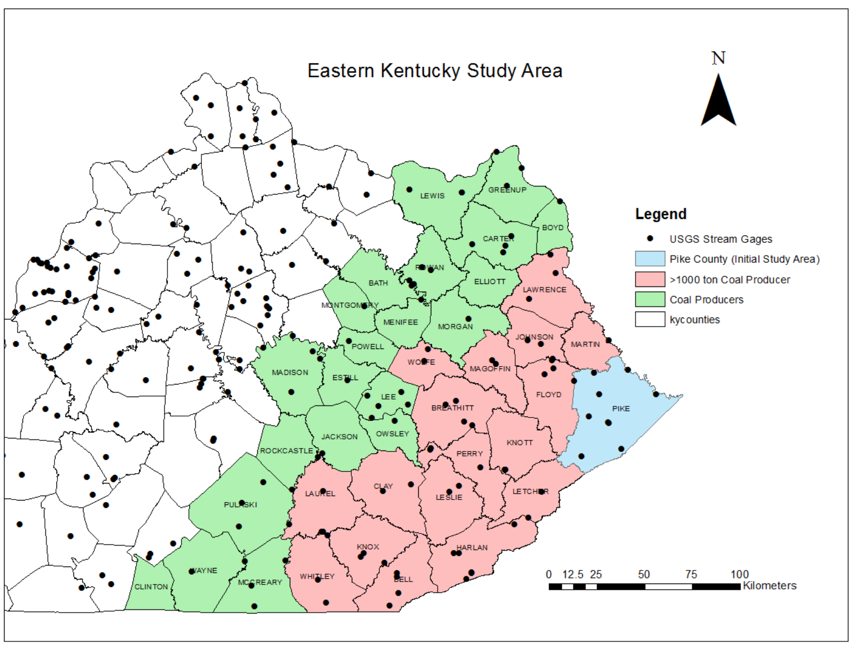
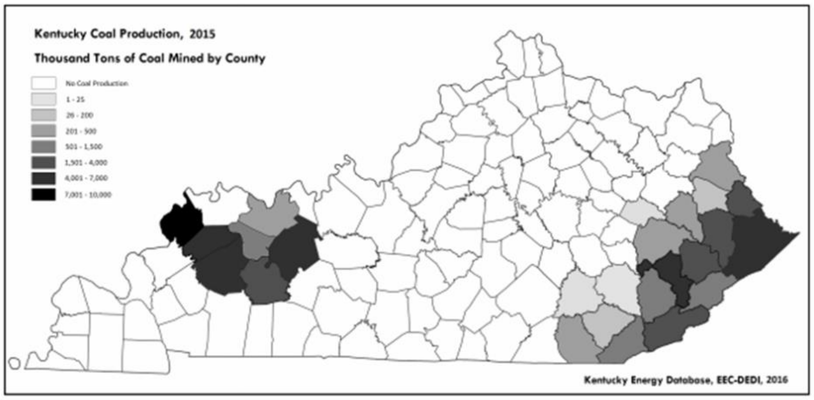


Figure 1. Study Area and USGS Stream Gauges.

Eastern Kentucky as a whole experienced a 25% reduction in coal production between 2014 and 2015, to about 28 million tons of coal. Since 2000, Eastern Kentucky coal production for surface and underground mining has decreased by 74%. The KY

Coal facts contains coal production and employment statistics to county level (Figure 2) which were used to determine other specific counties to focus efforts on determining appropriate land scape and river and stream characteristics for this study.

Kentucky Coal Production



County	Tons	1 Year Change	Percentage
Total	61,414,340	-20.8%	100%
Union	9,114,413	-29.77%	14.84%
Pike	6,926,940	-33.69%	11.28%
Hopkins	6,844,611	-15.3%	11.14%
Ohio	6,748,636	-19.05%	10.99%
Perry	6,652,760	-11.01%	10.83%
Webster	5,871,014	-8.24%	9.56%
Harlan	3,827,478	-20.08%	6.23%
Muhlenberg	3,567,732	-1.60%	5.81%
Floyd	2,148,884	-15.0%	3.50%
Knott	2,132,915	7.18%	3.47%
Martin	1,578,349	-22.76%	2.57%
Leslie	1,437,000	+2.40%	2.34%

County	Tons	1 Year Change	Percentage
Bell	1,382,103	-2.54%	2.25%
McLean	842,924	+281.57%	1.37%
Letcher	523,160	-68.27%	0.85%
Lawrence	373,375	-52.36%	0.61%
Daviess	334,672	+3.36%	0.54%
Magoffin	258,351	-78.58%	0.42%
Whitley	253,477	-33.58%	0.41%
Breathitt	251,064	-55.55%	0.41%
Knox	180,748	-54.13%	0.29%
Johnson	122,108	-39.95%	0.20%
Wolfe	24,444	+57.3%	0.04%
Laurel	8,668	-28.86%	<0.01%
Clay	8,514	-95.12%	<0.01%

Figure 2. 2015 Kentucky Coal Production (Kentucky Coal Facts 2016).

CHAPTER 3: DATA

3.1 Physical Data

A land cover data set gave a better understanding of how target areas are represented through land cover. This study used the National Land Cover Database from 2011 (updated in 2014). The NLCD contains 16 land cover classifications, at a spatial resolution of 30m in raster format. The classifications are water (open water and perennial ice/snow), developed (open space, low intensity, medium intensity, high intensity), barren, forest (deciduous, evergreen, and mixed forest), shrubland (dwarf scrub, shrub/scrub), herbacious (grassland, sedge, lichens, moss), planted/cultivated (pasture/hay, cultivated crops), wetlands (woody wetlands, emergent herbaceous wetlands. Landsat 5 Thematic Mapper provided the source imagery for this database, from which the imagery was classified into the specific land covers using decision tree algorithms (Homer et al. 2015). Additional land cover information used included Kentucky local road, state highway and transmission line data layers, downloaded from the Kentucky geo portal (Kentucky Geography Network 2018).

Elevation was important to this study in order to determine the hydraulic head of the streams. A digital elevation model with 1 arc-second (or 30 meter) resolution was used from the USGS National Elevation Dataset (NED 2018). The USDA GeoSpatial Data Gateway (USDA 2018) provided a download for this data.

Stream discharge information was needed for the study area obtained from the USGS National Water Information System (NWIS) which allows downloading of stream gauge discharge data, including peak instantaneous, daily, monthly, and annual statistics of discharge in cubic feet per second. This information can be downloaded into a table, graph, or table separated file.

The National Hydrography Dataset provided stream layer data in order to ensure that point locations for potential RoR sites could be directly identified with relation to known streams (NHD 2018). This database represents the water drainage network, and surface water features in the United States.

3.2 Population Data

Using the Census Estimates for 2016, population was used to assess the direct benefit for cities close to potential RoR systems (United States Census Bureau 2016). After calculating energy generation potential from the RoR systems, location and population information will aid in assessing how much of a nearby population could benefit from RoR distributed energy (Lei et al. 2009). Knowing the total kWh potential of RoR systems near populated areas will show the direct benefit of energy production that homes or businesses could use.

CHAPTER 4: METHODS

The success of RoR sites is dependent on how well an appropriate landscape is chosen and utilized. Rojanamon et al. (2009) laid a successful frame work for identifying suitable RoR systems in the Nan River Basin in India. As a result, many of their methods were used for this study in Eastern Kentucky to see if such an approach may be successfully developed elsewhere. Additionally, proposed methods from the USGS Preliminary Proposal (2015) were used. Determining site suitability requires watershed delineation, discharge, land cover and elevation data. The multiple spatial layers and information were combined in ArcGIS to select the best candidates for RoR systems.

Because of Pike County's recent decline in coal production indicated from Kentucky Coal facts (2016), along with the vast range of elevation changes, it was chosen as the focus for this analysis. Pike county elevation ranges from about 200 meters in the lowest elevation along the Western boundary, to the highest elevation of about 960 meters at the peak of Pine Mountain. Many towns, roads, and railways are located in the narrow ridges between the mountain peaks in Pike County (University of Kentucky 2014).

The National Hydrography Dataset was first loaded into arcmap and clipped to only include Pike County. The Generate Random Points tool generated points along the NHD flowlines at intervals of 250 meters to create individual site locations. The USGS Proposal suggested to check points every 100 meters, but this led to an inundation of point locations with very similar physical characteristics. The split lines at points tool next broke the NHD flowlines into 250 meter segments. Between each of these points, it was important to know the elevation change in that area of the stream.

The 30 meter DEMs identified the change in elevation across the county. Two DEMs were mosaicked to cover the entire county. The extract surface feature tool identified the minimum and maximum elevation to add to the 250 meter line segments along the stream network. To find the difference in elevation, the minimum z value was subtracted from the maximum z value and added as a z difference field to the point shape file. The intersect geoprocessing tool paired up the 250m lines and points that were generated. These points represented the un-edited potential locations for RoR systems.

The intersect geoprocessing tool produced many duplicate values from the overlapping 250 m points and split line segments, and excel processing further removed duplicate elevation differences. Before exporting the table to excel, the latitude and longitude were calculated so the points could be re added as a shapefile to arcmap.

After the points were added as a shapefile, they were next subsetted based on the land cover. A NLCD layer was clipped to Pike County, and then using the raster to Polygon tool, was converted to a vector layer. From this layer, a selection was performed to exclude urban development and agricultural land covers. There are many important structural components of the RoR systems such as the water intake weir, power house (small generator and connection to power grid), surge tank (for sudden changes in pressure), headrace and tail race (where water enters and leaves system), and penstock (small pipe used to deliver and control water flow to the power house) Rojanamon et al. (2009), (Figure 3). Ensuring there is available, undeveloped space is important for identifying locations to build RoR systems. Based on the NLCD selection, the 250m points were clipped to only include those that were located on the remainder of the NLCD shapefile.

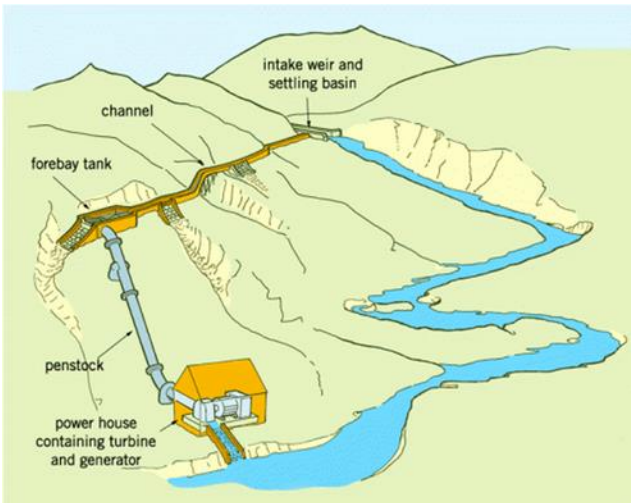


Figure 3. Run of River System Example (SSWM 2010)

In order to ensure the accessibility of RoR sites, they need to be geographically close to roads. Between road and transmission line GIS layers, the two were usually located right next to each other, as well as the rivers and streams. This study opted to clip the RoR potential sites that were within a kilometer of a road. The next subset was based on elevation difference. To expand the potential site selection, Elevation differences between 8 to 50 feet, or about 2.5 to 15 meters were selected. This ensured that the study had a proper elevation change for the RoR hydraulic head. In Table 1. below from the USGS Preliminary Proposal (2015) hydro plant classifications are correlated with hydraulic head height in feet, and the power capacity in megawatts (MW).

Plant Classification	Hydraulic Head (feet)	Power Capacity (MW)
Small	> 30ft	1-30 MW
Low-power	< 30ft	< 1 MW
Mini-hydro		100 kW-1 MW
Conventional	8-30ft	
Unconventional	< 8ft	
Micro-hydro	< 30ft	< 100kW

Table 1. Classification of small to micro hydroelectric plants (USGS Preliminary Proposal 2015).

To determine annual discharge, the most reliable method would be to directly use a stream gauge on the potential stream for the RoR system. There are 7 gauges within Pike County but not all have historical discharge data. Table 2. has information about each gauge.

Station #	Station Name	Drainage Area in km sqr	Historical discharge record
3210000	Johns Creek nr Meta, Ky	90.61 km	1941-2018
3209500	Levisa Fork @ Pikeville, Ky	1982.71 km	1938-2017
3207995	Fishtrap Lake nr Milliard, Ky	630.86 km	N/A
3208000	Levisa Fork below Fishtrap Dam nr Millard, Ky	630.86 km	1938-2000
3207965	Grapevine Creek nr Phyllis, Ky	9.98 km	1974-2016
3209300	Russell Fork @ Elkhorn City, Ky	891.58 km	1961-1992
3213700	Tug Fork @ Williamson, WV	1506.35 km	1968-2018

Table 2. Pike County Gauging Stations

Rojanamon et al. (2009) determined discharge using a regional flow duration model as there were no stream gauging sites located near the watershed being investigated for RoR systems. While the USGS gauge network is extensive, it will not cover every stream location needed in this study. To estimate discharge for streams that do not have an associated gauge, this study will use the Drainage-Area ratio method (Asquith et al. 2001). A ratio between the area draining to the known gauge and the ungauged site is first determined. The ratio is then multiplied by the known gauged discharge to find estimated discharge for the ungauged site. The formula to determine the drainage-area ratio is as follows. (Equation 1)

$$Y = X\,(A_y/A_x)^{\varphi} \qquad (1)$$

Y = The stream flow of the ungauged location.

X = The stream flow of the gauged location.

A_y = Drainage Area for ungauged location

A_x = Drainage Area for Gauged location

$\varphi = 1$, showing the method is a direct proportion.

To verify this method can accurately estimate the annual discharge for ungauged sites, the drainage area ratio method was calculated against known gauged sites to show it could reasonably estimate discharge. Table 3. shows the testing gauge sites used, and Table 4. shows the reference gauge to be used for the drainage-area ratio method. These gauges are located within or adjacent to the same county for this study and represent similar biophysical conditions. They are also the only gauges of the 7 in Pike County that have necessary long term annual discharge data (1981-2010).

	Gage#	Area (km2)	Area Ratio to Levisa Fork	Observed Ann Q (cms)	Estimated Ann Q (cms)	Estd-Obs Q
St Johns	3210000	145.8	0.046	1.75	1.79	0.04
Tug Fork	3214500	3315.2	1.039	40.8	40.62	-0.18
N Fk Kent	3277500	1206.9	0.378	15.1	14.79	-0.31

Table 3. Test gauge sites for drainage-area ratio method.

Levisa Fork Area (km2)	3190.9
Levisa Fork Ann Q (cms)	39.1

Table 4. Levisa Fork area and cms discharge.

In order to calculate drainage area and then discharge for the potential RoR sites, the 30 meter DEM created a fill, flow direction, and flow accumulation layer. With the flow accumulation layer, it is possible to determine which pixels of a raster contribute to segments of streams in a watershed. Using the extract value to points tool, the drainage area in pixels is added as a file to each of the 250 meter points. Area in kilometers is calculated which gave the drained area for each of the associate points. There were many small drainage areas, so the layer was subsetted further to only include those with at least 1 kilometer drainage area. This information was exported into excel for further analysis.

Using the drainage-area ratio method, annual discharge was calculated in cubic meters per second for each potential RoR location. Finally, power was calculated using the Oregon State University (2002) power calculations, suggested by the USGS preliminary proposal (2015). Power is determined by multiplying discharge by the specific weight of water, and by the hydraulic head (ft) (Equation 2). Energy is then further determined by multiplying power by a time interval (kWh) (Equation 3).

$$\text{Power} = \text{Discharge (cfs)} * \text{Specific Weight of water } (61.4 \text{ lbf/ft}^{3)}) * \text{Hydraulic Head (ft)} \quad (2)$$

$$\text{Energy} = \text{Power} * \text{time interval (kWh)} \quad (3)$$

CHAPTER 5: RESULTS

Table 5. shows the highest kWh calculation for potential RoR sites for sites with over 1km drainage area. For a full list of potential RoR locations, see appendix. Based on the Area-Drainage ratio method, there were varying discharge rates with the highest reporting about 1 to 2 cubic feet/second (csf), or .01 to .05 cubic meters/second (cms).

z_diff (feet)	km_sqr	area ratio to levisa	estimated cms	cfs	cfs*head*specific weight of water (lbf-ft/s)	divided by 550lbft-ft/s = Horsepower	1hp=.746 KW	annual kWh
44.054	3.6963	0.001158388	0.045292968	1.617606	4446.74967	8.0849994	6.0314096	52,835.15
32.6363	4.8798	0.001529286	0.059795099	2.135539	4349.036585	7.907339245	5.8988751	51,674.15
41.9669	1.7361	0.000544078	0.021273468	0.759767	1989.62738	3.617504328	2.6986582	23,640.25
16.4981	4.2219	0.001323106	0.051733458	1.847623	1902.094088	3.458352888	2.5799313	22,600.20
44.7643	1.4157	0.000443668	0.017347416	0.619551	1730.585862	3.146519749	2.3473037	20,562.38
38.8652	1.6074	0.000503745	0.01969643	0.703444	1705.984153	3.101789369	2.3139349	20,270.07
25.1135	2.4768	0.000776207	0.030349707	1.083918	1698.588988	3.088343614	2.3039043	20,182.20
30.1223	2.034	0.000637438	0.024923815	0.890136	1673.128126	3.042051137	2.2693701	19,879.68
42.4391	1.4157	0.000443668	0.017347416	0.619551	1640.693733	2.983079514	2.2253773	19,494.31
33.1167	1.782	0.000558463	0.021835908	0.779854	1611.554048	2.930098269	2.1858533	19,148.07

Table 5. Highest ten kWh results.

The drainage area for these potential RoR locations were very small, with the largest having an area just over 4 sq. km. When looking directly at the potential RoR sites, of the two best results, one location had a hydraulic head of 32 feet with a higher cfs of 2.1, and the next had a hydraulic head of 44 feet, and a lower cfs of 1.6. Respectively, these had an annual power generation of 52,835 kWh and 51,674 kWh based on the estimation from the average annual discharge from the Levisa Fork Gauge near Pikeville. Based on the plant classification from the USGS Preliminary Proposal (2015), these two sites would be a micro-hydro classification as they produce less than 100 kW. If the discharge for these areas was greater, they could be classified as a small hydro-power plant because their hydraulic head is above 30 feet and could potentially have greater than 1 MW power generation. Compared to the average estimated household energy use by the U.S. Energy Information Administration (2015), the average house hold uses just under 11,000 kWh a year, each of these two sites only produce about 52,000 kWh annually.

Paw Paw City is nearest to Site 1, and Kimper City is closest to Site 2. Both are listed as a “populated place” bv the Geographic Names Information System (2018) and do not seem to be included in the latest census estimates (United states Census 2016). Figures 4. and Figure 5. show aerial imagery of the areas taken from google maps showing the terrain close to the potential RoR sites identified in this study. Figure 6. shows where all of the potential RoR sites are located, along with the best candidates and the cities closest to them.

Figure 4. Paw Paw city (Google Maps 2018).

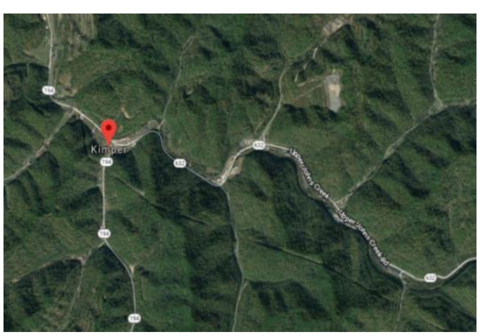


Figure 5. Kimper City (Google Maps 2018).

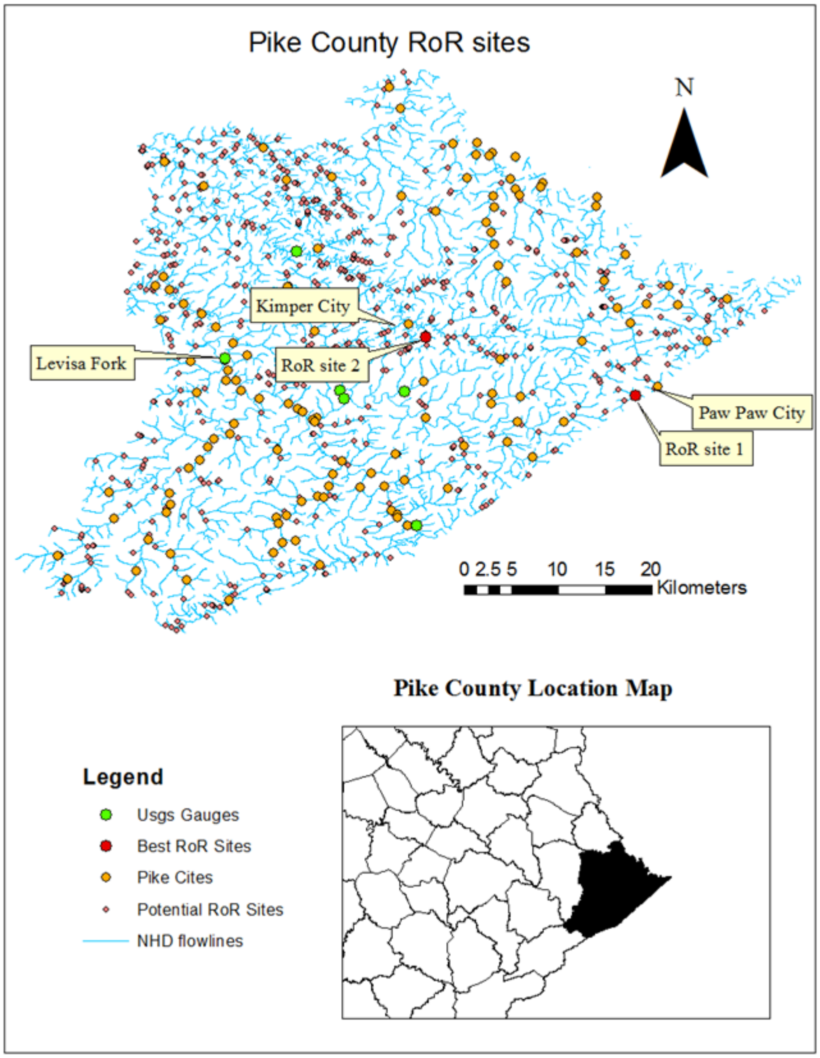


Figure 6. Pike County RoR sites.

There is a drastic elevation contrast throughout Pike County including low elevation areas with some of the bigger rivers like Levisa or Russel Fork in the Western region, and the higher peaks of the mountain ranges throughout the county. While the elevation change is important to have a hydraulic head high enough to produce electricity, most of the potential RoR sites were located on small streams that would only have a few square kilometers of drainage area due to the contrasting landscape. The lower energy generation of a RoR hydro-power plant in these regions would not be worth the costs of initial infrastructure development if it couldn't only support itself, or one other home with power.

CHAPTER 6: DISCUSSION

6.1 Limitations

While Pike County did not yield any candidates for further study to develop RoR systems, there proved to be potential for using GIS to determine appropriate locations for RoR implementation. Elevation, land cover, and annual discharge were the important factors in originally determining potential locations. Many levels of sub setting were implemented to ensure the locations had appropriate elevation change, relative closeness to roadways, and were not being placed within developed or agricultural areas. It would be simple to extend this procedure to other areas in the United States for future studies. This should be very evident based on the success of other RoR projects such as in the Nan River Basin from Rojanamon et al. (2009), or studies from Oregon State University (2002). The use of the Drainage-Area Ratio Model for this study was an efficient way to estimate discharge for ungauged locations. Originally the plan for this study was to follow the suggestion of the USGS preliminary Proposal and use the USGS StreamStats program (StreamStats Version 3, 2015). Using StreamStats, it is possible to delineate basins, compute basin characteristics, and compute flow statistics like peak and average annual flow estimations. The program is well supported, and has specific algorithms based on different states. StreamStats has a batch processing tool that allows the user to submit a shapefile with up to 200 points and then calculate the desired statistics from those points. However, StreamStats become a major shortfall with this project as a method to estimate discharge at unknown sites. When using the batch processing tool, it was important to ensure that generated points of interest were snapped to the streamgrid that was provided by USGS StreamStats. After submitting the shapefile, the data is placed in a queue and a confirmation email is sent out. The queue can take several days to get through, and it does not always return all data points. Because the program is limited to 200 points at a time, large scale studies would need to plan in advance while StreamStats processes, or ensure that the shapefile point layer was properly subsetted to a manageable amount of points. StreamStats was not the best option for this study as there were originally several hundred potential RoR candidates locations. If the study was to focus on smaller watersheds that had specific interest from the population and governance, StreamStats batch processing would be a more adequate tool.

6.2 Future Studies.

For locations with a suitable landscape for RoR systems, the next step would be to further evaluate the discharge for the region. Monthly average, peak, and minimum flow are important to ensure RoR systems can run on a year round basis to be efficient. The drainage area ratio method may not be a suitable method to estimate discharge on a monthly scale, so further research, and potential site visits would be necessary at this point.

RoR systems are implemented for their lower cost and small environmental impact, but there will still be some form of impact that should be accounted for. Anderson et al. (2015), looked at site specific considerations to assess issues like water flow disruption from the weir, or disruption from the tailrace where water reenters the stream. Considerations on maintenance and construction were also assessed regarding their potential for disruption. Their paper assessed multiple studies and the impact from various sizes of dams and RoR systems. Comparing between the potential and size of RoR system locations identified by this study, and examples of impact given by Anderson et al. (2015), Site 1 and Site 2 did not meet the energy generation to relate to the given examples. Some of the expected disruptions that could occur with a higher discharge and energy output would be reduction in species population between the head and tailrace, known as the depleted stretches. Examples given by Anderson et al. (2015) indicated small spawning fish were found absent, mayfly populations reduced, and one example showed drops in salmonid populations from RoR systems of less than 1MW generation in Europe. If a weir was used to divert stream flow, many migratory aquatic species were also hindered. While the RoR potential sites in this study had a very small energy potential, their expected impact would be similar because the water diversion is a key part of the RoR systems. As suggested by Anderson et al. (2015), the environmental impact would be an important part of the RoR system into the future as it would need to be monitored, and especially tailored to fit each system.

While coal development is in a decline, as indicated by the yearly Kentucky Coal Facts report, some mines within Pike County are also set to reopen. The Southern Coal Corporation, for example, plans to reopen some mines to restart production again. This is exciting for individuals who previously relied on the lost jobs from the coal mines that were closed (McCauley 2017). But as some companies suggest, coal is not always an option for sustainable income or energy into the future. Additional sources of energy through RoR hydro power systems is not an option for Pike County, but there are other ideas that have been given attention. Berkley Energy Group, a Pike County company, is studying the potential to implement solar power fields in the unused strip mining locations. The company's goal would be a 50 to 100 MW solar farm, making it the biggest in Kentucky, and the first large scale solar energy farm in Appalachia (Estep 2017; Bruggers 2017). They are working with EDF Renewable energy who have implemented 885 megawatts of solar projects in North America. If the studies show promising potential, EDF would be financing the project. The goal of implementing solar power into eastern Kentucky would still not be to replace coal, but as all of the coal has been extracted in some of their strip mining locations, the project could add additional sources of revenue and employment for populations that have relied heavily on coal in the past.

6.3 Conclusion

In conclusion, the objective of this study to use GIS to locate potential locations for RoR systems was achieved, although it was identified that Pike County in Eastern Kentucky did not meet the criteria, so my hypothesis was not supported. The landscape has plenty of elevation change to produce an artificial hydraulic head to meet energy production needs, but there was not enough associated discharge for RoR systems to be efficient. Much of Pike County has varying elevation change due to the mountain ranges, and the sharp contrast could be part of the issues with discharge, as many of the streams segments with a good hydraulic head only had a few square km of drainage area. While Pike County in Eastern Kentucky did not have suitable physical characteristics, other regions should be investigated for RoR potential to continue to expand the use of sustainable energy resources in the U.S.

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APENDIX

z_diff (feet)	km_sqr	area ratio to levisa	estimated cms	cfs	cfs*head*specific weight of water (lbf-ft/s)	divided by 550lbft-ft/s = Horsepower	1hp=.746 KW	annual kWh
44.054	3.6963	0.001158388	0.045292968	1.617606	4446.74967	8.0849994	6.0314096	52,835.15
32.6363	4.8798	0.001529286	0.059795099	2.135539	4349.036585	7.907339245	5.8988751	51,674.15
41.9669	1.7361	0.000544078	0.021273468	0.759767	1989.62738	3.617504328	2.6986582	23,640.25
16.4981	4.2219	0.001323106	0.051733458	1.847623	1902.094088	3.458352888	2.5799313	22,600.20
44.7643	1.4157	0.000443668	0.017347416	0.619551	1730.585862	3.146519749	2.3473037	20,562.38
38.8652	1.6074	0.000503745	0.01969643	0.703444	1705.984153	3.101789369	2.3139349	20,270.07
25.1135	2.4768	0.000776207	0.030349707	1.083918	1698.588988	3.088343614	2.3039043	20,182.20
30.1223	2.034	0.000637438	0.024923815	0.890136	1673.128126	3.042051137	2.2693701	19,879.68
42.4391	1.4157	0.000443668	0.017347416	0.619551	1640.693733	2.983079514	2.2253773	19,494.31
33.1167	1.782	0.000558463	0.021835908	0.779854	1611.554048	2.930098269	2.1858533	19,148.07
39.1895	1.4769	0.000462847	0.018097336	0.646333	1580.559811	2.87374511	2.1438139	18,779.81
31.2256	1.845	0.000578207	0.022607885	0.807424	1573.248348	2.860451541	2.1338968	18,692.94
33.0911	1.6668	0.00052236	0.020424294	0.729439	1506.207541	2.738559165	2.0429651	17,896.37
31.3663	1.737	0.000544361	0.021284497	0.760161	1487.829728	2.705144961	2.0180381	17,678.01
26.6832	2.0205	0.000633207	0.024758391	0.884228	1472.268052	2.676851003	1.9969308	17,493.11
26.3819	2.0169	0.000632079	0.024714278	0.882653	1453.049996	2.641909083	1.9708642	17,264.77
30.519	1.6668	0.00052236	0.020424294	0.729439	1389.13327	2.525696854	1.8841699	16,505.33
48.9381	1.0269	0.000321821	0.012583218	0.449401	1372.351558	2.495184651	1.8614077	16,305.93
45.2119	1.0962	0.000343539	0.013432392	0.479728	1353.420274	2.460764134	1.83573	16,081.00
34.5199	1.4328	0.000449027	0.017556953	0.627034	1350.657466	2.455740847	1.8319827	16,048.17
16.156	3.033	0.000950516	0.037165157	1.327327	1338.124051	2.432952819	1.8149828	15,899.25
37.5302	1.2942	0.000405591	0.015858604	0.566379	1326.393534	2.411624607	1.799072	15,759.87
35.6263	1.3221	0.000414335	0.016200479	0.578589	1286.249289	2.338635071	1.7446218	15,282.89
44.7462	1.044	0.00032718	0.012792754	0.456884	1275.694784	2.319445062	1.730306	15,157.48
38.6562	1.1511	0.000360745	0.014105115	0.503754	1215.128859	2.209325197	1.6481566	14,437.85
31.081	1.3545	0.000424488	0.016597496	0.592768	1149.645952	2.090265367	1.559338	13,659.80
25.6962	1.5993	0.000501207	0.019597176	0.699899	1122.248317	2.040451486	1.5221768	13,334.27
36.4143	1.0656	0.00033395	0.013057432	0.466337	1059.635011	1.926609112	1.4372504	12,590.31
36.9478	1.0323	0.000323514	0.012649387	0.451764	1041.560816	1.893746938	1.4127352	12,375.56
18.1097	1.9908	0.000623899	0.024394459	0.871231	984.5301259	1.790054774	1.3353809	11,697.94
24.3119	1.4499	0.000454386	0.017766489	0.634517	962.602693	1.750186715	1.3056393	11,437.40
11.4842	2.9412	0.000921746	0.036040277	1.287153	922.3917847	1.677075972	1.2510987	10,959.62
15.5562	1.9908	0.000623899	0.024394459	0.871231	845.7096222	1.537653859	1.1470898	10,048.51
28.4526	1.071	0.000335642	0.013123601	0.4687	832.1498725	1.512999768	1.1286978	9,887.39
26.4435	1.1178	0.000350309	0.01369707	0.489181	807.1851507	1.467609365	1.0948366	9,590.77
14.9902	1.8927	0.000593156	0.023192381	0.828299	774.7816586	1.408693925	1.0508857	9,205.76
25.3606	1.1034	0.000345796	0.013520618	0.482879	764.1570524	1.389376459	1.0364748	9,079.52
20.2296	1.0638	0.000333386	0.013035376	0.465549	587.6752534	1.068500461	0.7971013	6,982.61
18.3129	1.1682	0.000366104	0.014314651	0.511238	584.2038941	1.062188898	0.7923929	6,941.36
19.2505	1.0539	0.000330283	0.012914065	0.461217	554.0277783	1.007323233	0.7514631	6,582.82
17.8755	1.0962	0.000343539	0.013432392	0.479728	535.103902	0.972916185	0.7257955	6,357.97
17.203	1.1214	0.000351437	0.013741183	0.490757	526.8110342	0.957838244	0.7145473	6,259.43
12.4394	1.5093	0.000473001	0.018494353	0.660513	512.7021362	0.932185702	0.6954105	6,091.80
10.8254	1.3941	0.000436899	0.017082738	0.610098	412.1240903	0.749316528	0.5589901	4,896.75
8.54128	1.2555	0.000393463	0.01538439	0.549442	292.8395952	0.532435628	0.397197	3,479.45

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